GRAPH OF COMPONENTS IN GIBBSITE-KAOLINITE-TYPE BAUXITE

BY G. C. BRANNER

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SUMMARY

The bauxite diagram presented as figure 1 was developed to clarify, by graphic means, the theoretical chemical constituents of gibbsite-kaolinite-type bauxite for all possible proportions of these two minerals from pure gibbsite to pure kaolinite. The tables in the report reflect the same data.

The diagram provides (1) a graphic representation of the relations of constituents with respect to all possible percentages of alumina and silica, (2) a basis for verifying the accuracy of analyses of gibbsite-kaolinite bauxite, and (3) a basis for estimating the type and proportion of alumina hydrate and/or silicate minerals that may be present in gibbsite-kaolinite-type bauxite. The diagram, with accompanying interpretations and use formulas, will be useful to those connected with the mining and processing of bauxite.

INTRODUCTION

The commercial bauxite produced in the United States, Surinam, and British Guiana consists almost entirely of gibbsite and kaolinite, with small percentages of iron and titanium minerals. The commercial value of the ores depends very largely upon the relative amounts of gibbsite and kaolinite they carry. The standard (triacid) method of analyzing bauxite gives values of alumina, silica, and combined water. The alumina and combined water are common to both minerals, whereas the silica exists in the kaolinite only. A graphic representation of these several relations in all possible combinations and a formulation and tabulation of these relations are presented.

DISCUSSION

The diagram shown in figure 1 represents the theoretical constituents of bauxite varying from 100 percent gibbsite (alumina trihydrate) to 100 percent kaolinite (hydrated alumina silicate). No other aluminous minerals are considered. Other constituents that dilute these two constituents, such as Fe_2O_3, FeO, TiO_2, and SiO_2 as free silica or other minerals, are not shown, although the method by which their total modifies the use of the diagram is discussed hereafter.

The assumed formula for gibbsite is $Al_2O_3 \cdot 3H_2O$ and for kaolinite $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$.

The theoretical percentage, by weight, of the alumina and water constituents of gibbsite is shown on the baseline A-B. The maximum percentage of Al_2O_3 on line A-B is therefore 65.35, the theoretical percentage of Al_2O_3 contained in gibbsite. Percentages of SiO_2, which, for purposes of this diagram, occur exclusively in the kaolinite, are shown at the left on line A-C, the maximum of which is 46.54.

The percentages of total Al_2O_3 (the Al_2O_3 in gibbsite added to the Al O in kaolinite) for different percentages of SiO_2 are indicated by line D-E, which is the right side of the area B-F-G superimposed on area A-C-D. It follows that the total percentage of Al_2O_3 cannot exceed 65.35 percent, the percentage of Al_2O_3 in gibbsite, or be less than 39.50 percent, the percentage of Al_2O_3 in kaolinite.

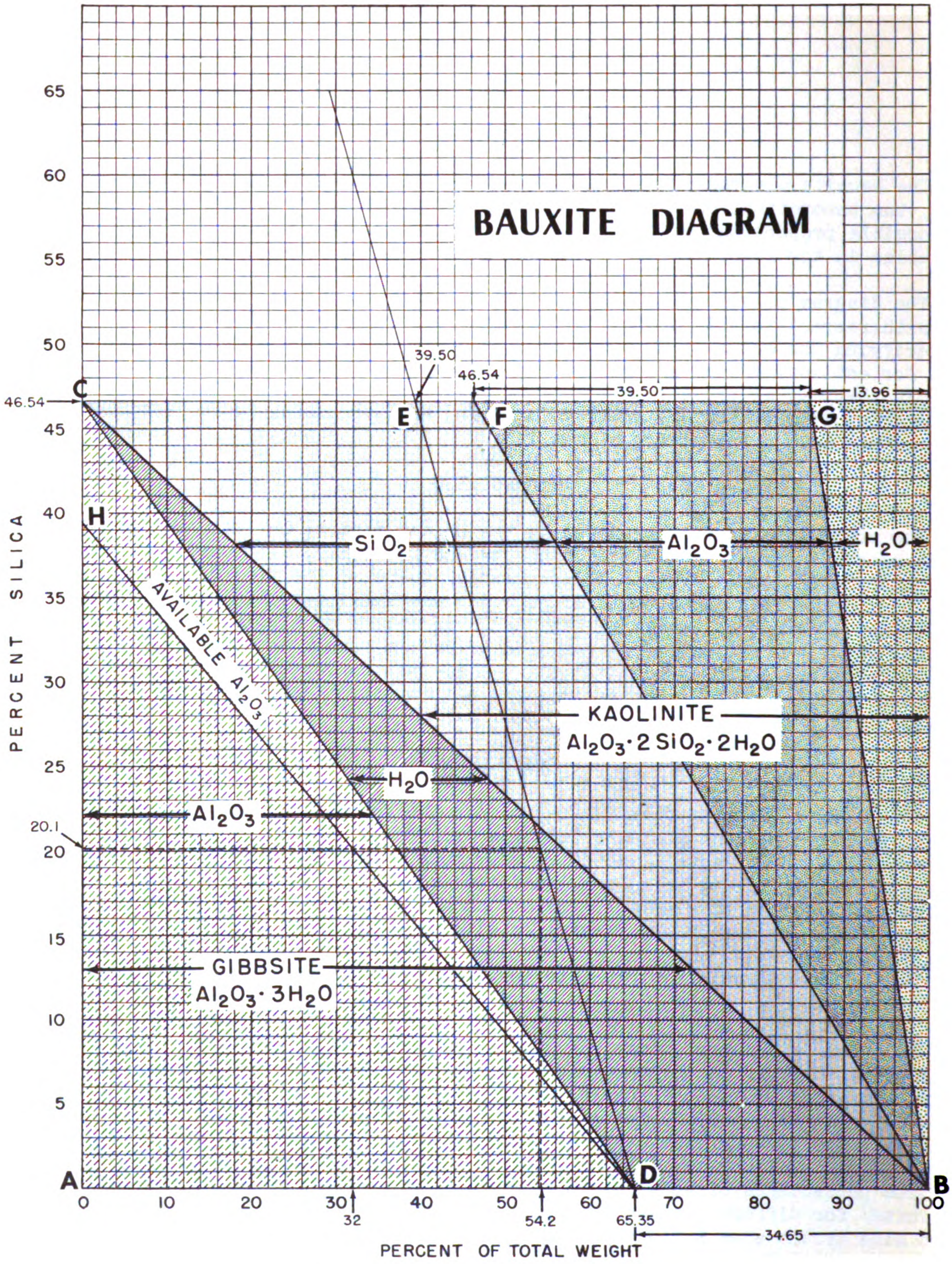

Figure 1. - Bauxite diagram.

To use the diagram, the percentage of Al_2O_3 given in an analysis is extended vertically from line A-B to the total Al_2O_3 line, D-E, and the corresponding SiO_2 is then read to the left on line A-C.

Since the percentage of Al_2O_3 that is available for recovery by the Bayer process has been empirically determined to average 1.1 multiplied by the percentage of SiO_2, as given in an analysis subtracted from the percentage of the total percentage of Al_2O_3 as given in an analysis, line D-H is drawn to indicate that fact and permits the percentage of Al_2O_3 that is available for any given percent of SiO_2 to be read on line A-D. It develops from this relation that when the available percentage of Al_2O_3 is at the allowable lower limit of 32 and no diluents are present, the SiO_2 equals 20.1 percent, the maximum allowable, and the percentage of total Al_2O_3, 54.2 percent. As will be shown, when diluents are present this maximum SiO_2 decreases 0.39 percent from 20.1 percent for each percentage of total diluents present.

When diluents are present, the diagram is altered, as shown in figure 2.

It is, of course, possible to construct a diagram for each percentage of total diluent minerals. However, the present diagram may be used if adjustment factors are applied. These are derived below.

The following constants are used:

1. Al_2O_3 in gibbsite - 65.35 percent.
2. Al_2O_3 in kaolinite - 39.50 percent.
3. SiO_2 in kaolinite - 46.54 percent.
4. Maximum spread for Al_2O_3 content = (1) - (2) = 25.85.
5. (3) ÷ (4) = 1.80.
6. (4) ÷ (3) = 0.56.

With reference to factors 5 and 6, it should be noted that for each percentage change in Al_2O_3 content shown on line A-B there will be a corresponding change of 1.80 percent of SiO_2 content on line A-C, and conversely for each percentage change of SiO_2 on line A-C there will be a corresponding change of 0.56 percent of Al_2O_3 on line A-B.

With no diluents present, the percentage of SiO_2 corresponding to a given percentage of Al_2O_3 is expressed in the following equation:

$$\text{Percent } SiO_2 = \frac{46.54}{25.85} \times (65.35 - \text{percent } Al_2O_3)$$

$$\text{or } = 1.8 \times (65.35 - \text{percent } Al_2O_3); \qquad (1)$$

similarly, the percentage of Al_2O_3 corresponding to a given percentage of SiO_2 is expressed in the following equation:

$$\text{Percent } Al_2O_3 = 65.35 - (\text{percent } SiO_2 \times \frac{25.85}{46.54})$$

$$\text{or } = 65.35 - 0.56\ (\text{percent } SiO_2) \qquad (2)$$

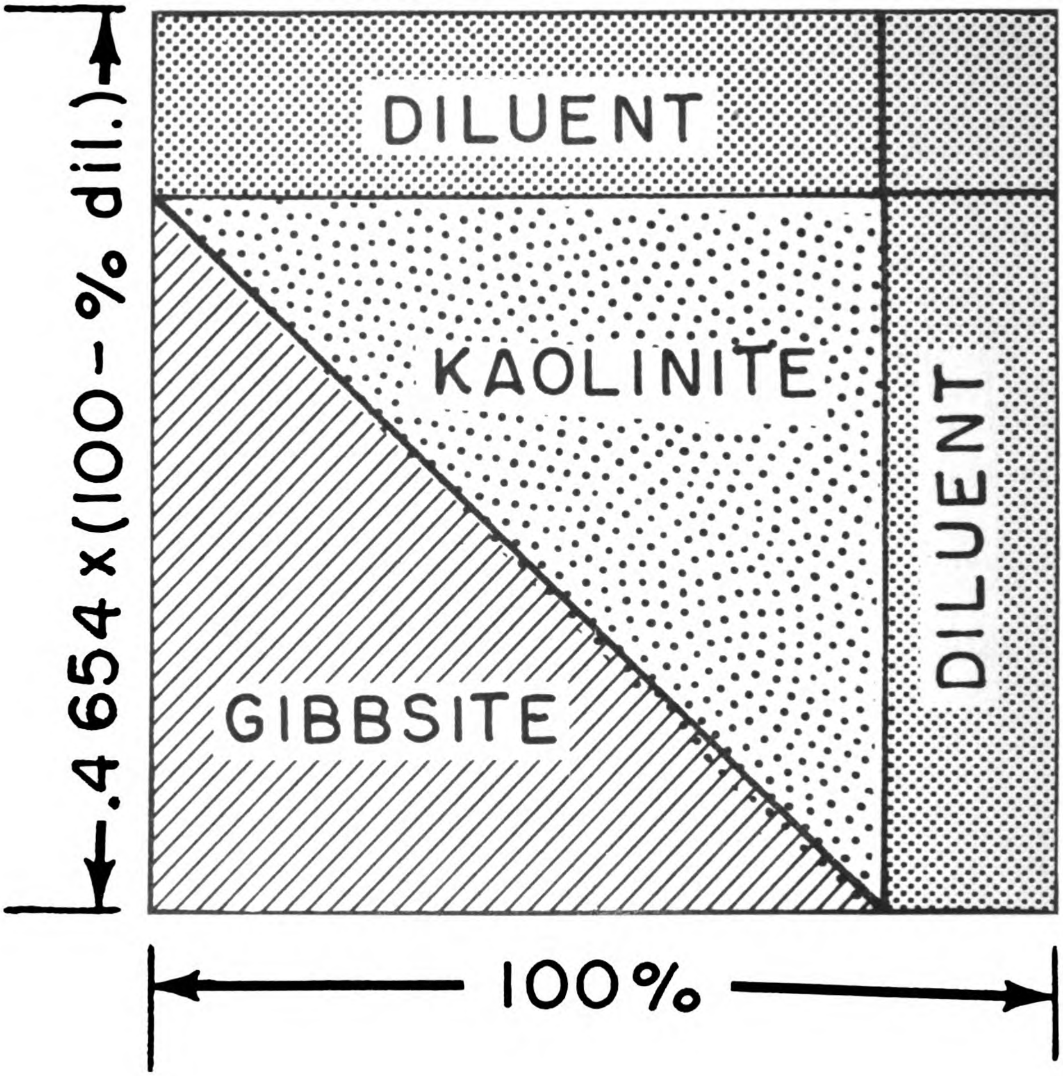

Figure 2. - Effect of diluents on bauxite diagram.

Since diluents such as Fe_2O_3, FeO, TiO_2, or free silica are always present in some amount, the total of which is referred to herein as "dil," it becomes necessary to make an adjustment of the SiO_2 percentage reported in an analysis in order to be able to read the theoretical corresponding value of the percentage of Al_2O_3 on line A-B. This is accomplished as follows:

$$\text{Adjusted percent } SiO_2 = [0.6535\ (100 - \text{percent dil}) - \text{percent } Al_2O_3] \times \frac{46.54}{25.85},$$

$$\text{or } = 1.8\ [[0.6535\ (100 - \text{percent dil})] - \text{percent } Al_2O_3]; \quad (3)$$

in which 0.6535 x (100 - percent dil) cannot be smaller than percent Al_2O_3.

Similarly, percent Al_2O_3 is adjusted as follows:

$$\text{Adjusted percent } Al_2O_3 = [0.6535\ (100 - \text{percent dil})] - \text{percent } SiO_2 \times \frac{25.85}{46.54},$$

$$\text{or } = [0.6535\ (100 - \text{percent dil})] - 0.56\ (\text{percent } SiO_2); \quad (4)$$

in which 0.6535 (100 - percent dil) cannot be smaller than 0.56 percent SiO_2.

In determining the sum of the diluents it should be noted that[2] when the triacid method of analysis is used, all iron present is expressed as a percentage of Fe_2O_3 and that, emirically, this should be multiplied by the factor 1.38 to correct for loss on ignition of the hydrated oxides or of the carbonate or both. If FeO is given separately, the percentage should be corrected by multiplying by 1.54.

As the difference between formulas (1) and (3) is due to diluents only, calculations using the same percentage of Al_2O_3 in each indicate that for each percentage of diluent present the theoretical SiO_2 is reduced by 1.18 percent. For example:

Assuming 50 percent Al_2O_3 and applying (1), we have

$$\text{percent } SiO_2 = 1.8\ (65.35 - 50) = 27.630 \text{ percent},$$

and assuming 50 percent Al_2O_3 and 10 percent diluent, we have

$$\text{percent } SiO_2 = 1.8\ [(0.6535 \times 90) - 50] = 15.867 \text{ percent}.$$

Subtracting 15.867 from 27.630 gives 11,763 percent, which when divided by 10 gives a percentage SiO_2 loss for each percent of diluent of 1.18. Therefore, to adjust the SiO_2 percentage to read the theoretical corresponding Al_2O_3 percentage value, the percentage of the total diluent should be multiplied by 1.18 and the result added to the SiO_2 percentage indicated in the analysis. It will be noted that when the total diluent is 39.50 percent, the SiO_2 becomes 46.54 percent, the theoretical limit. Beyond that point the figures are mathematical factors obtained by the extension of line D-E and corresponding Al_2O_3 percentage values can be read on line A-B.

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[2] Malamphy, M. C., Dale, G. K., Romslo, T. M., Reed, A. H., Jr., Ollar, A., and Tracey, J. I., Jr., Investigation of Arkansas Bauxite. Vol. I: Bureau of Mines Rept. of Investigations 4251, 1948, 63 pp.

As an example, the following analysis of a dried bauxite sample is assumed:

percent Al_2O_3 = 55.7 (partly in gibbsite, partly in kaolinite),

percent SiO_2 = 11.6 (in kaolinite),

[3] percent Fe_2O_3, etc. = 5.0 (total of all diluents),

percent H_2O = 27.7 (partly in gibbsite, partly in kaolinite).

To arrive at the SiO_2 percentage from the diagram that must be used to find the corresponding percentage of Al_2O_3, 5.0 is multiplied by 1.18 = 5.9 percent. This is added to the 11.6 giving the SiO_2 value of 17.5 percent. From this the corresponding correct Al_2O_3 percentage may be read as approximately 55.7 from line A-C to line D-E and to line A-B. This checks with the analysis given.

As has been referred to above, when no diluents are present,

$$\text{Available percent } Al_2O_3 = \text{percent } Al_2O_3 - 1.1\ (\text{percent } SiO_2) \qquad (5).$$

For the minimum of 32 percent of available alumina, the maximum allowable theoretical SiO_2 is 20.1 percent. In the limiting case when the Al_2O_3 = 32 percent and SiO_2 = 0 percent, the diluents must be $\frac{32.00}{65.35}$ or 51.03 percent. However, when no diluents are are present it may be shown that the SiO_2 percentage must be 20.1 percent and the Al_2O_3 percent 54.1 percent when the available Al_2O_3 is at 32 percent. Therefore the average rate of decrease of SiO_2 from 20.1 percent to 0 percent is $\frac{20.1}{51.03}$, or 0.39 percent for each percent of diluent. The formula, then, for maximum percentage of SiO_2 with 32 percent of available Al_2O_3 is,

$$\text{Maximum percent } SiO_2 \text{ for 32 percent available } Al_2O_3 = 20.1\% - 0.39\ (\%\ \text{dil}) \qquad (6)$$

in which dil cannot exceed 51.03 percent. The corresponding formula for Al_2O_3 then becomes,

$$\text{Minimum percent } Al_2O_3 \text{ for 32 percent available } Al_2O_3 = 32\% + 1.1\ (\%SiO_2), \qquad (7)$$

in which SiO_2 cannot exceed 20.1 percent.

Since the diagram, as modified by adjustments for the total of diluents present, accurately represents the relative constituents of gibbsite-haolinite-type bauxite, variations from these relations in an analysis indicate that one or more other aluminous minerals must be present. The following explanations are given to account for variations:

1. When the figures reported in a series of analyses are consistently higher than those obtained from the diagrams or tables, boehmite ($Al_2O_3 \cdot H_2O$) is present in some amount. This has an Al_2O_3 percentage of 84.98, which is materially higher than that of gibbsite, $Al_2O_3 \cdot 3H_2O$ (65.35), and/or an aluminum silicate (clay) mineral is present that has a higher percentage of Al_2O_3 than kaolinite (39.50).

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[3] Corrected for loss on ignition.

2. When the figures reported in a series of analyses are consistently lower than those obtained from the diagram or tables, the explanation appears to be that since no alumina hydrate mineral is known to exist with a lower percentage of alumina than in gibbsite (65.35), an aluminum silicate (clay) mineral is present with a lower percentage of Al_2O_3 than that contained in kaolinite (39.50). For example, halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 3H_2O$), which is a common associate of kaolinite, has an Al_2O_3 percentage of 36.92.

To provide tabular equivalents of the above data, tables 1 and 2 are added. Table 1 gives the adjustments of the percentage of SiO_2 that must be made for each percentage of total diluent given in an analysis. The adjusted percentage of SiO_2 is then referred to table 2, and the corresponding theoretical percentage of Al_2O_3 can then be found.

The adjusted SiO_2 figures in table 1 are only given to the approximate limit, which will provide 32 percent of available Al_2O_3 at different percentages of SiO_2. It will be noted that the SiO_2 figures go to 60.0, which is above 46.54 percent, the theoretical maximum possible SiO_2 in kaolinite. Above that latter value, the figures are mathematical factors only but will give the correct corresponding Al_2O_3 percentage values.

As an example of the use of the table, using the analysis of dried bauxite referred to above, the SiO_2 figure of 11.6 percent is read to the right on the top line under 11 percent. In this column, the figure for 5.0 percent diluents is given as 16.9, which, when interplated to 11.6 percent SiO_2, becomes 17.5 percent. This figure is found in the SiO_2 percent, column in table 2, and by interpolation the corresponding Al_2O_3 figure is found to be 55.7 percent, which checks with the analysis.

TABLE 1. - Adjusted percentage of SiO_2 for corresponding theoretical Al_2O_3

Total diluents percent	Percent SiO_2, as reported in analysis, percent																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0
1	2.2	3.2	4.2	5.2	6.2	7.2	8.2	9.2	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.2	18.2	19.2	20.2	21.2	22.2
2	3.4	4.4	5.4	6.4	7.4	8.4	9.4	10.4	11.4	12.4	13.4	14.4	15.4	16.4	17.4	18.4	19.4	20.4	21.4	22.4	23.4
3	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
4	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7	18.7	19.7	20.7	21.7	22.7	23.7	24.7	
5	6.9	7.9	8.9	9.9	10.9	11.9	12.9	13.9	14.9	15.9	16.9	17.9	18.9	19.9	20.9	21.9	22.9	23.9	24.9		
6	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1	24.1	25.1	26.1		
7	9.3	10.3	11.3	12.3	13.3	14.3	15.3	16.3	17.3	18.3	19.3	20.3	21.3	22.3	23.3	24.3	25.3	26.3	27.3		
8	10.4	11.4	12.4	13.4	14.4	15.4	16.4	17.4	18.4	19.4	20.4	21.4	22.4	23.4	24.4	25.4	26.4	27.4			
9	11.6	12.6	13.6	14.6	15.6	16.6	17.6	18.6	19.6	20.6	21.6	22.6	23.6	24.6	25.6	26.6	27.6	28.6			
10	12.8	13.8	14.8	15.8	16.8	17.8	18.8	19.8	20.8	21.8	22.8	23.8	24.8	25.8	26.8	27.8	28.8				
11	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0				
12	15.2	16.2	17.2	18.2	19.2	20.2	21.2	22.2	23.2	24.2	25.2	26.2	27.2	28.2	29.2	30.2	31.2				
13	16.3	17.3	18.3	19.3	20.3	21.3	22.3	23.3	24.3	25.3	26.3	27.3	28.3	29.3	30.3	31.3					
14	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	32.5					
15	18.7	19.7	20.7	21.7	22.7	23.7	24.7	25.7	26.7	27.7	28.7	29.7	30.7	31.7	32.7						
16	19.9	20.9	21.9	22.9	23.9	24.9	25.9	26.9	27.9	28.9	29.9	30.9	31.9	32.9	33.9						
17	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1	30.1	31.1	32.1	33.1	34.1	35.1						
18	22.2	23.2	24.2	25.2	26.2	27.2	28.2	29.2	30.2	31.2	32.2	33.2	34.2	35.2							
19	23.4	24.4	25.4	26.4	27.4	28.4	29.4	30.4	31.4	32.4	33.4	34.4	35.4	36.4							
20	24.6	25.6	26.6	27.6	28.6	29.6	30.6	31.6	32.6	33.6	34.6	35.6	36.6								
21	25.8	26.8	27.8	28.8	29.8	30.8	31.8	32.8	33.8	34.8	35.8	36.8	37.8								
22	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0								
23	28.1	29.1	30.1	31.1	32.1	33.1	34.1	35.1	36.1	37.1	38.1	39.1									
24	29.3	30.3	31.3	32.3	33.3	34.3	35.3	36.3	37.3	38.3	39.3	40.3									
25	30.5	31.5	32.5	33.5	34.5	35.5	36.5	37.5	38.5	39.5	40.5										
26	31.7	32.7	33.7	34.7	35.7	36.7	37.7	38.7	39.7	40.7	41.7										
27	32.9	33.9	34.9	35.9	36.9	37.9	38.9	39.9	40.9	41.9	42.9										
28	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0											
29	35.2	36.2	37.2	38.2	39.2	40.2	41.2	42.2	43.2	44.2											
30	36.4	37.4	38.4	39.4	40.4	41.4	42.4	43.4	44.4												
31	37.6	38.6	39.6	40.6	41.6	42.6	43.6	44.6	45.6												
32	38.8	39.8	40.8	41.8	42.8	43.8	44.8	45.8	46.8												
33	39.9	40.9	41.9	42.9	43.9	44.9	45.9	46.9													
34	41.1	42.1	43.1	44.1	45.1	46.1	47.1	48.1													
35	42.3	43.3	44.3	45.3	46.3	47.3	48.3														
36	43.5	44.5	45.5	46.5	47.5	48.5	49.5														
37	44.7	45.7	46.7	47.7	48.7	49.7	50.7														
38	45.8	46.8	47.8	48.8	49.8	50.8															
39	47.0	48.0	49.0	50.0	51.0	52.0															
40	48.2	49.2	50.2	51.2	52.2																
41	49.4	50.4	51.4	52.4	53.4																
42	50.6	51.6	52.6	53.6	54.6																
43	51.7	52.7	53.7	54.7																	
44	52.9	53.9	54.9	55.9																	
45	54.1	55.1	56.1																		
46	55.3	56.3	57.3																		
47	56.5	57.5	58.5																		
48	57.6	58.6																			
49	58.8	59.8																			
50	60.0																				
51	61.2																				
52	61.0																				

1. Interpolation

SiO_2 reported, percent (line 1)	Add to SiO_2 (line 1)
+0.1	0.1
.2	.2
.3	.3
.4	.4
.5	.5
.6	.6
.7	.7
.8	.8
.9	.9

2. Interpolation

Dilutent, percent	Add to adjusted SiO_2 (in table)
+0.1	0.1
.2	.2
.3	.4
.4	.5
.5	.6
.6	.7
.7	.8
.8	.9
.9	1.0

TABLE 2. - Percentage of SiO_2 and corresponding percentage of Al_2O_3 in gibbsite-kaolinite with no diluents

SiO_2, percent	Al_2O_3, percent	SiO_2, percent	Al_2O_3, percent
0	65.4	32	47.8
1	64.8	33	47.2
2	64.3	34	46.7
3	63.7	35	46.1
4	63.2	36	45.6
5	62.6	37	45.0
6	62.1	38	44.5
7	61.5	39	43.9
8	61.0	40	43.4
9	60.4	41	42.8
10	59.9	42	42.3
11	59.3	43	41.7
12	58.8	44	41.2
13	58.2	45	40.6
14	57.7	46	40.1
15	57.1	47	39.5
16	56.6	48	39.0
17	56.0	49	38.4
18	55.5	50	37.9
19	54.9	51	37.3
20	54.4	52	36.8
21	53.8	53	36.2
22	53.3	54	35.7
23	52.7	55	35.1
24	52.2	56	34.6
25	51.6	57	34.0
26	51.1	58	33.5
27	50.5	59	32.9
28	50.0	60	32.4
29	49.4	61	31.8
30	48.9	62	31.3
31	48.3		

Interpolation

SiO_2 percent	Subtract from Al_2O_3
0.1	0.1
.2	.1
.3	.2
.4	.2
.5	.3
.6	.3
.7	.4
.8	.4
.9	.5